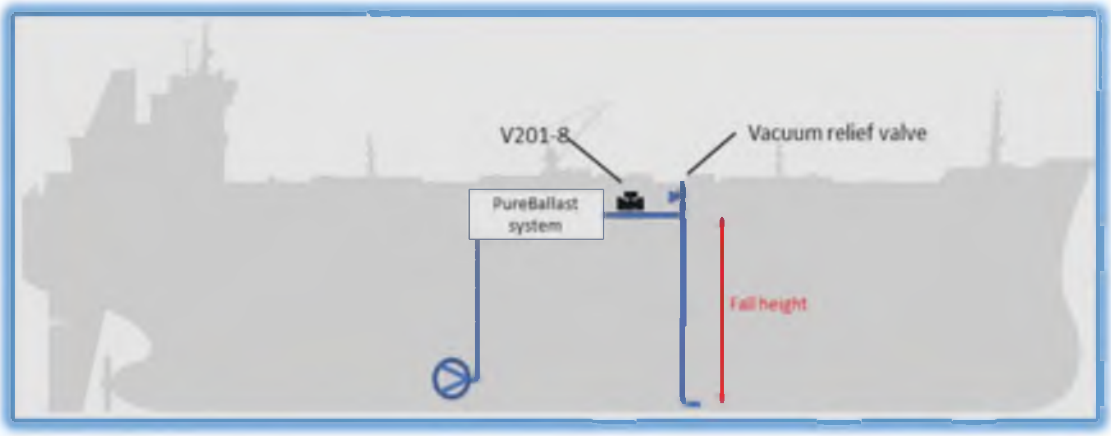

Figure 13 – Ballast systemoverview

To solve the problems with cavitation and vacuum, the system should beequipped with vacuum relief valves:

- **VB201** In pipe 201. Float operated vacuum relief valve providing both air releaseupon startup of the system and vacuum relief during operation.
- **VB309**In pipe 309. Only vacuum relief, without air venting function. The valveis spring loaded (normally closed) to avoid water spillage during initiationof back-flush.

5. Conclusion

In order to prevent ecological and environmental disasters, ship owners must comply with the Ballast Water Management Convention.

The article shows that one of the most efficient, modern and flexible BWTS combines initial filtration with enhanced UV treatment in a specially designed reactor. This system has has a large spectrum of species that he is eliminating without being harmful to the environment.The system with is using UV lamps is safe to handle and to be operated by the crew. There are no additives to the process that could harm the vessel or equipment onboard.

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RESEARCH OF TRIBOLOGICAL PROPERTIES OF COATINGS OF PISTON RINGS OF A MARINE INTERNAL COMBUSTION ENGINE

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The article is devoted to the analysis of changes in the tribological properties of ship engine piston ring coatings obtained using different coating methods. The analysis of the rate and nature of wear of the coatings of piston

rings of a marine internal combustion engine using a multilayer nanostructured coating was carried out. Due to the deposition of thin protective coatings with a thickness from several tens of nanometers to several hundreds of micrometers, it becomes possible to achieve improved physical-mechanical, tribological and functional properties of various parts, assemblies and mechanisms, as well as significantly affect the performance characteristics of materials and significantly increase their service life. The experiment was carried out on the example of piston rings of an internal combustion engine, on which a multilayer coating of TiN / ZrN and MoN / CrN was applied. As part of the first experiment, to assess the degree of increase in the wear resistance of rings using equipment of the Bulat type, a multilayer ion-plasma coating of the TiN / CrN system was applied. In the second experiment, a CrN / MoN multilayer coating was carried out , which was deposited by cathode-arc deposition (Arc-PVD) using a Bulat-6M vacuum-arc unit. The size of the castle and the coercive force were chosen as the observed parameters. Taking into account the obtained physico-mechanical and tribological properties of TiN / ZrN and MoN / CrN multilayer nanostructured coatings, it can be argued that they are promising for further industrial use as protective coatings for metal products operating under high temperatures and under the influence of significant mechanical loads.
Keywords: piston rings, deposition, ion-plasma coating, durability, lock, cast iron, tribological characteristics

ИССЛЕДОВАНИЕ ТРИБОЛОГИЧЕСКИХ СВОЙСТВ ПОКРЫТИЙ ПОРШНЕВЫХ КОЛЕЦ СУДОВОГО ДВИГАТЕЛЯ ВНУТРЕННЕГО СГОРАНИЯ

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Статья посвящена проведению анализа изменений трибологических свойств покрытий поршневых колец судовых двигателей, полученных с использованием разных методов нанесения покрытий. Проведен анализ скорости и характера износа покрытий поршневых колец судового двигателя внутреннего сгорания при использовании многослойного наноструктурного покрытия. Благодаря осаждению тонких защитных покрытий толщиной от нескольких десятков нанометров до нескольких сотен микрометров возникает возможность достигнуть улучшенных физико-механических, трибологических и функциональных свойств разнообразных деталей, узлов и механизмов, а также заметно повлиять на эксплуатационные характеристики материалов и существенным образом увеличить срок их службы. Эксперимент проводился на примере поршневых колец двигателя внутреннего сгорания, на которые наносилось многослойное покрытие TiN/ZrN и MoN/CrN. В рамках первого эксперимента для оценки степени повышения износостойкости колец с использованием оборудования типа «Булат» было нанесено многослойное ионно-плазменное покрытие системы TiN/CrN. Во втором эксперименте было осуществлено многослойное покрытие CrN/MoN, которое осаждалось методом катодно-дугового осаждения (Arc-PVD) с использованием вакуумно-дугового блока Булат-6М. В качестве наблюдаемых параметров был избран размер замка и коэрцитивная сила. С учетом полученных физико-механических и трибологических свойств многослойных наноструктурных покрытий TiN/ZrN и MoN/CrN можно утверждать об их перспективности при дальнейшем промышленном использовании в качестве защитных покрытий для металлических изделий, работающих под действием высоких температур и под влиянием значительных механических нагрузок.
Ключевые слова: поршневые кольца, осаждение, ионно-плазменное покрытие, долговечность, замок, чугун, трибологические характеристики

Ensuring high tribological characteristics of special equipment parts by improving production methods is an important direction for improving the quality and reliability of their use. Piston rings are one of the most critical engine parts. Strengthening such thin-walled products by traditional methods does not ensure their stable quality, taking into account difficult operating conditions [1]. Wear of piston rings is a complex physical and mechanical process and requires the development of special solutions to improve their wear resistance.

The indicated circumstances actualize discussions and scientific developments in the direction of creating protective coatings with improved properties for parts, elements and parts of technical systems operating in aggressive environments.

Tribological properties of piston rings, the technology of chromium plating with subsequent processing by a plasma beam has become widespread. However, this approach requires the presence of two different conditions for conducting operations and equipment for such strengthening [2]. In addition, chrome plating implies the need to ensure the environmental safety of personnel, as well as the protection of surfaces that cannot be strengthened.

New, more advanced technologies involve the use of a multilayer nanostructured coating. It is due to the deposition of thin protective coatings with a thickness of several tens of nanometers to several hundred micrometers that it becomes possible to achieve improved physical, mechanical, tribological and functional properties of various parts, assemblies and mechanisms, as well as significantly affect the performance of materials and significantly increase their service life [3].

For example, vacuum arc and magnetron deposition of coatings is a promising method for obtaining multicomponent and multilayer nanostructured coatings based on transition metal carbonitrides or nitrides [4]. The use of multilayer coatings contributes to a significant improvement in the physico-mechanical and tribological properties of parts due to the presence of a two-phase structure and a large number of interphase boundaries that prevent the movement of dislocations and, thus, prevent the destruction of the material [5].

Thus, taking into account the foregoing, the determination of the general patterns and features of the formation of the structural-phase state of multilayer and multicomponent protective coatings of piston rings based on carbides or nitrides of transition and refractory metals, understanding the aspects of the influence of deposition conditions and post-condensation processing on the tribological properties of these coatings, are an urgent task of modern solid state physics and materials science, which determines the choice of the topic of this article.

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A great contribution to the development of tribology was made by Kiseleva S.K., Zaripov N.G., Shcherbakova O.O., Muravyova T.I., Zhang, Ziruo; Xiao, Ruitao; Yang, Xiao.

Novikov A.D., Tarapanov A.S., Selemenev M.F., Tao, Xian - Sen worked on the development and use of nano -coatings in various technical systems; Sun, Yong - Gang; Xu, Yan - Song; Liu, Yuan.

However, despite the existing publications and developments, we note the fact that surface modification technologies, among which the most popular technologies for applying wear-resistant coatings, are relatively new, therefore, in the subject plane of their practical application, there is still a whole range of unresolved issues. In particular, the analysis of the influence of the conditions of use of thin-walled parts, the stability of their material and key characteristics during friction and wear under conditions of changing parameters in operation deserves special attention.

Also, experimental and theoretical approaches for evaluating the features of structural changes in materials during friction and wear need to be clarified.

So, the circumstances indicated above allow us to formulate the purpose of the article as follows - to investigate changes in the tribological properties of piston ring coatings obtained using different coating methods and different chemical elements.

So, the object of research is the process of wear of oil scraper piston rings of the diesel engine before and after their hardening. Two different coatings and deposition methods were used for quenching.

As part of the first experiment, to assess the degree of increase in the wear resistance of rings using equipment of the Bulat type, a multilayer ion-plasma coating of the TiN / CrN system was applied . The deposition of the coating was carried out at the arc current I = 100 A, the bias voltage of the substrate was U = - 200 V . A total of 7 layers of 5-TiN and CrN were gradually deposited with preliminary deposition of pure Cr , the thickness of which was 50 nm. As a result, the thickness of the 1st TiN layer is 49 nm, and that of CrN is 240 nm. The CrN / TiN ratio reached 5.8. The total thickness of the multilayer coating is 1.7 nm (including the chromium sublayer).

Work on monitoring changes in the size of the piston ring lock and the degree of residual stresses was carried out for 2 months, the frequency of observation was 6-8 days. Special zones were chosen for the experiment (I, II and III, see Fig. 1). The measurements were carried out using different batches of gray cast iron piston rings.

Fig. 1 – Areas for observing changes in piston ring lock size and coercive force

Oscillations of the stress-strain state of the ring, in terms of coercive force, were analyzed before and after deposition of the reinforcing coating. Based on the results of the experiment, it was concluded that after applying the CrN / TiN coating, depending on the specific evaluation period in the selected measurement zones, it was possible to observe changes in the dimensions of the castle and the level of coercive force. According to the author, these changes are due to the formation of residual stresses during hardening treatments.

Table 1 shows the results of measurements of the value of interlocks before coating with TiN /CrN, as well as after coating, when the first and last measurements were taken.

Table 1 – Value of interlocks before and after coating with TiN / CrN

Sample number	Before coating, mm	After coating, mm (1st measurement)	After coating, mm (last measurement)
one	92	89	90
2	93	90	91
3	94	88	107

The measurement results, which are presented in table 1, indicate that after the first measurement, the size of the lock in all observed samples decreased - No. 1 and No. 2 by 3.2%, No. 3 by 6.3%. The last measurement recorded the fact that the size of the lock in ring No. 1 decreased by 2.1%, in sample No. 2 it also decreased by a similar amount, but in sample 3 it increased by 13.8% compared to the level before processing.

Table 2 reflects the readings of the dynamics of the coercive force at the beginning and at the end of the experiment in the observed coverage areas.

Table 2 – Changes in the coercive force in the observed zones after deposition of the TiN/CrN coating

Sample number	After coating, A/cm (1st measurement)				After coating, A/cm (last measurement)			
	I	II	III	Mean	I	II	III	Mean
one	12.5	12.5	13.1	12.8	12.1	12.4	12.6	12.3
2	17.7	17.9	20.7	18.8	17.2	17.3	20.3	18.2
3	15.5	14.8	15.3	15.2	14.7	14.9	14.4	14.7

Measurements of the coercive force indicate that during natural wear, the level of residual stresses decreased, on average, by 3.9%, 3.2% and 3.28% for rings No. 1, No. 2 and No. 3, respectively, this allows us to state that the coating technology under consideration helps to reduce the stress in the piston rings after they have been strengthened.

Now we will analyze the coercive force and changes in the size of the piston ring lock according to the results of the second experiment.

In the second experiment, a CrN / MoN multilayer coating was carried out , which was deposited by cathode-arc deposition (Arc-PVD) using a Bulat-6M vacuum-arc unit. Films were deposited with dimensions of 20 × 20 mm and a thickness of 2 mm. Prior to the deposition process, the surface was cleaned and activated by ion bombardment by applying a negative potential of -1.3 kV for 15 minutes.

The cleaning process was carried out with continuous rotation of the test samples, while the arc current was equal to I_{arc} 120 A and 100 A for Cr (99% pure cathode) and Mo (99.99% pure cathode), respectively. First, a thin layer of pure metals was deposited on the rings for 1 minute, and the main deposition process of CrN / MoN multilayer films was carried out in a nitrogen atmosphere for up to 1 hour.

The deposition time of each layer varied from 300 to 80 seconds from sample 1 to sample 3, while the other deposition conditions were kept unchanged (see Table 3).

Table 3 – Deposition conditions for CrN / MoN coatings for piston rings

Sample number	I_{arc} BUT		Displacement potential, V	p, Pa	Layer deposition time, s	Number of layers
	MoN	CrN				
one	120	100	-twenty	0.4	300	12
2					150	25
3					80	45

The coatings contain from 12 to 45 layers depending on the deposition conditions, and the thickness of a single layer varies from tens of nanometers to 1.1 μm, while the total film thickness is from 7.8 to 14.7 μm.

Table 4 contains piston ring lock measurement results before and after coating.

Table 4 – Interlock dimensions before and after CrN / MoN coating

Sample number	Before coating, mm	After coating, mm (1st measurement)	After coating, mm (last measurement)
one	92	92	92
2	93	103	106
3	94	106	100

After treatment of the rings with CrN / MoN coating, the value of the lock in the first sample did not change, while the deviations of indicators 2 and 3 of the sample are more significant compared to the results of the first experiment, when treatment was carried out with TiN / CrN . So, the value of the lock of the piston ring No. 2 after the first measurement increased by 11%, and after the second it increased by another 3.33%. With the third sample, the deviation of the lock value after the first measurement reached 13.2%, but after the second, the difference decreased and was fixed at 5.66%.

Table 5 shows the results of the first and last measurements of the coercive force in the three observed zones after CrN / MoN coating .

Table 5 – Coercive force fluctuations in three measurement zones after CrN / MoN coating

Sample number	After coating, A/cm (1st measurement)				After coating, A/cm (last measurement)			
	I	II	III	Mean	I	II	III	Mean
one	12.1	12.2	12.3	12.1	11.6	11.5	11.6	11.5
2	16.6	16.7	21.2	18.1	19.7	19.8	18.8	18.1
3	14.7	13.9	15.7	14.7	16.8	13.5	13.4	14.5

The dynamics of the coercive force presented in Table 5 allows us to draw the following conclusions:

– the level of residual stresses in the first sample decreased by an average of 5%, which is a good indicator;

– residual stresses in the second sample remained unchanged;

– residual stresses in the third sample decreased slightly, their decrease was 1.3%

Thus, the results of processing CrN / MoN piston rings, in terms of the possibility of reducing stresses in them, indicate low efficiency compared to the TiN / CrN coating.

So, summing up the results of the study, we can draw the following conclusions.

Both investigated series of TiN / ZrN and MoN / CrN multilayer coatings and methods of their application indicate that the value of the piston ring lock significantly fluctuates after processing, which does not meet the established requirements and regulatory documents. At the same time, the results of measuring the dynamics of the coercive force of piston rings allow us to conclude that after deposition of a multilayer coating on them, their durability tends to increase.

Taking into account the obtained physico-mechanical and tribological properties of TiN / ZrN and MoN / CrN multilayer nanostructured coatings , it can be argued that they are promising for further industrial use as protective coatings for metal products operating under high temperatures and under the influence of significant mechanical loads.

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